LCA Methodology

Environmental Assessment of Products

The Ranges of the Societal Preferences Method

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Abstract

The evaluation of product alternatives in Life Cycle Analysis (LCA) is a critical step on the basis of results as related to their impact category data. Decisions involving several environmental issues are hardly ever straightforward, since one alternative only seldom clearly dominates the others in all aspects. More often, one alternative scores better on some environmental issues and worse on others. A combination of impact data and preferences is then required for evaluation. This can be done using evaluation methods based on fixed societal preferences. However, by applying different evaluation methods to the same data, different "best" alternatives may be chosen. This reduces the credibility of LCA results.

Instead of fixed societal preferences an approach has been developed which uses consensus-oriented ranges of societal values for specifying the ranking of the overall environmental attractiveness of alternatives. These ranges may indicate both the uncertainty of decision-makers and the shifting of societal values, e.g. as related to the dynamics of knowledge of environmental problem areas.

In this article, an approach is proposed which combines environmental data and uncertain societal values to form a clear statement on alternatives regarding their overall damage. By using a full set of potentially relevant societal preferences, a merely coincidental selection of the best product alternative is ruled out. A step-by-step procedure, narrowing down the feasible range of societal preferences, has been developed. The approach is illustrated using a case study of TV-housing concepts and a survey.

Keywords: Case study; environmental assessment; method for environmental alternative ranking; societal preference method; TV-housing concept

1 Introduction

The purpose of an LCA is to record all relevant input and output flows of considered alternatives over the whole life cycle and to estimate their related potential environmental harm. This approach is used for a direct comparison of alternatives, i.e. their evaluation.[1]

Several methods have been developed to make a recommendation concerning the alternatives analysed. All the methods are based on different, but fixed societal values. Therefore, the application of different approaches may lead to the choice of different "best" alternatives. This damages the credibility of environmental decision-making in LCA.

In order to achieve a clear and reproducible outcome, distributions of uncertain societal preferences are used for the comparative evaluation of environmental profiles. The uncertain and often qualitative nature of inventory and characterisation data is not taken into account here. We concentrate on the uncertain nature of evaluation.

2 Decision Making Methods in LCA

2.1 Information supplied by LCA

In LCA the choice of the preferred alternative or the complete ranking of alternatives has to be made on the basis of information obtained from inventory analysis and impact assessment. In the inventory analysis, one can distinguish between the product alternatives analysed and input and output flows such as 1) (a)biotic resource depletion, 2) emissions of substances into air, water and soil (including emissions of radioactivity and noise) and 3) land use. (A)biotic resource deple-

[1] The step called *evaluation* or *weighting across impact categories* in this paper is defined by the SETAC as *valuation* and in the ISO framework as *weighting*. These are the respective definitions:
SETAC: "*Valuation* is the step in which the contributions from the different impact categories are weighted so that they can be compared among themselves." (Consoli et al., 1993)
ISO: "*Weighting* aims to rank, weight, or possibly aggregate the results of different life cycle impact assessment categories in order to arrive at the relative importance of these different results." (ISO, 1997)
The step termed *evaluation* in the ISO framework is different, since it refers to the acceptability of the result and includes such tools as a completeness check, sensitivity check and consistency check. We use the term evaluation because it is customarily related to decision-making theory.

tion and emissions into air, water and soil are taken into account in full LCA and LCIs. The information is available on a cardinal scale, leaving out uncertainties and other qualitative aspects.

Nevertheless, qualitative data should be included in an LCA (LINDFORS et al., 1995, Deutsches Institut für Normung, 1994, p. 210). In order to increase transparency in LCA, qualitative information should be transformed into quantitative information (HOFSTETTER, 1996, pp. 133-135; HEIJUNGS et al., 1992, p. 54). This is in line with the application of decision-making methods, as long as the number of quantitative aspects is significantly greater than the number of qualitative ones (YOON and HWANG, 1995). In this context, we investigate the uncertainty in evaluation by quantifying it.

2.2 Principles of evaluation

In recent years, up to thirty different methods have been developed for identifying the most environmentally friendly product alternative (HOFSTETTER, 1996, p. 203). All the existing methods have differences in the methodological approaches and societal preferences applied. Below, we use "evaluation" in the sense of ISO to cover the "weighting of impact categories" and part of "interpretation" (ISO 14040, 1996).

It turns out that all methods – implicitly or explicitly – are based on different societal values. Mostly it is not possible to trace the origin of how these values have been chosen. These, frequently numerous values are fixed for a number of methods. One example is the method of critical volumes, where values are fixed on a substance level. For this reason, it is not surprising that different methodological approaches choose different "best" alternatives based on exactly the same inventory data (BAUMANN and RYDBERG, 1992; NOTARNICOLA et al., 1998). The choice of the "best" alternative is quite likely to depend on the choice of impact assessment and evaluation method, even within the restrictions of the SETAC framework and the preliminary results of ISO standardisation (1997).

For this reason, requirements have been developed in order to make the whole selection process of the most environmentally friendly product alternative well-founded. The two main criteria are transparency and reproducibility of the decision-making process. These main requirements are particularly fulfilled by a clear distinction between environmental profile and societal preferences. In order to identify the best alternatives, these types of information have to be combined.

2.3 Decision making theory in LCA

So far, LCA methodology, and in particular the interpretation phase, have been developed with a weak link to decision-making theory[2] (SETAC, 1992; HEIJUNGS, 1994; EDWARDS and NEWMANN, 1982). Statements based on LCAs are therefore difficult to interpret and hotly disputed (LUNDIE, 1999, pp. 76-79). This weakness can be reduced by applying decision-making methods:

- The use of decision-making methods can increase the transparency and comprehensiveness of results. Furthermore, the decision-making process is more structured and gives the decision-maker a more detailed insight into specific parts of the whole decision-making process.
- A well-structured decision-making process facilitates the consideration of more independent items of information. According to MILLER (1967), a decision-maker can process seven plus/minus two types of information, e.g. input, output flows or impact categories, at the same time. This number is often exceeded in LCA (ISO 14042, 1997; SETAC, 1992; HEIJUNGS et al., 1992). Then *ad hoc decisions* are usually made by focusing on some aspects and leaving out others.
- The application of decision-making methods can support the decision-making process in LCA in order to make it more intersubjective and to increase acceptance of the LCA outcome (HOFSTETTER, 1996, pp. 158-159).

2.4 Combination rule for environmental information and societal preferences

According to HOFSTETTER (1996), there are mental reservations concerning the use of decision-making methods in the context of environmental problems. Decision-makers often agree with every single step of a decision-making method, but they disagree with the resulting outcome (HOFSTETTER, 1996, p. 159). Because of this, and the requirements for evaluation (→ *Chapter* 2.2), the focus here is on a method which is easy to apply, transparent and broadly accepted in decision-making theory.

However, the decision-making problem in LCA belongs to the group of multi-criteria analysis (MCA). Generally, multi-criteria decision-making (MCDM) is characterised by three aspects:

1) several criteria to be judged on
2) decision-making variables
3) a process of comparing alternatives.

In MCDM, one can distinguish between multi-attributive decision-making (MADM) and multi-objective decision-making (MODM) (HWANG and YOON, 1981, pp. 2-4; WEBER, 1993, p. 11).

[2] Decision-making theory is made up of a *group of models* which consist of one or more decision-makers, an environment of the decision-makers, one or more rational decision maxims and a "value-system" (GÄFGEN, 1974).

Decision-making is a multi-attributive problem if a finite number of discrete alternatives is given, attributes (e.g. impact categories) are given explicitly, criteria are defined by attributes, and the goal of the decision-making process is the evaluation and selection of alternatives. In contrast to this, multi-objective problems are characterised by an infinite number of continuous alternatives, explicitly given objectives, and criteria defined by objectives. The purpose is to design alternatives (HWANG and YOON, 1981, p. 4). Therefore, most LCAs, and also the case study described below, belong to the MADM group.
Allowing for the requirements of LCAs and decision-making theory, LUNDIE (1998) analysed the available decision-making methods taking cardinal information into account. The simple additive weighting method (SAW-method) had been selected as the most appropriate method for combining inventory data/impact category scores with preferences of decision-makers (LUNDIE, 1998, pp 178-186).
For each alternative, the SAW-method calculates an environmental index by multiplying normalised environmental data with the societal preferences, and finally summing up these terms (HWANG and YOON, 1981, pp 99-103). The normalised data involved here states the contribution of the case to an impact category as a share of the total contribution of society to that category in one year.[3]

$$Index_i = \sum_{j=1}^{n} normalized\_score_j * societal\_preference_j \qquad \text{(eq. 1)}$$

with i = alternative
j = impact category

The smallest index calculated indicates the most environmentally friendly product alternative which causes the least overall environmental damage according to the preferences of the decision-makers.

Although the environmental contributions can then be calculated, the question of which societal preferences should be used is still open.

2.5 Uncertainty on societal preferences

One can distinguish between different bases of information for societal preferences:

1. The *preferences* are *fully unknown* concerning the importance of impact categories. In this case, a decision has to be made on the pure environmental profile of alternatives.

2. Bounded set of preferences ("*Ratio 10*"): "Ratio 10" means that the ratio between the most and least important environmental issue is smaller than 10, e.g. global warming potential is never ten times more important than acidification potential and vice versa. This is valid for existing surveys (HUPPES et al., 1997; HERRCHEN and KLEIN, 1994; LUNDIE, 1998; WALZ et al., 1996). It can be used as a first approximation as long as no societal preferences are available.

3. Application of *ranges of societal preferences*. The uncertainty is expressed by ranges of preferences. The ranges are given, e.g. by surveys.

4. If there is detailed knowledge of and agreement on societal preferences, *fixed societal values* can be applied. There are several ways to arrive at a set of societal preferences, e.g. from political statements, revealed preferences, governmental aims, individual aims, sustainability criteria, and surveys (HUPPES et al., 1997). Of course, each way would probably lead to different fixed sets.

If societal preferences are available, one particular weighting set of societal preferences is usually used as a basis for identifying the most environmentally friendly product alternative. However, looking at existing surveys or deduced preferences, it turns out that achieving fixed, generally accepted societal preferences is unrealistic. Moreover, societal values are dynamic. They depend on the decision-makers asked, the time of the survey, and the knowledge of the environmental problem area considered. Therefore, societal values are always uncertain. Nevertheless, the specific societal preferences are used to identify the most environmentally friendly product alternative. The relationship between different levels of information on societal preferences is shown in diagram form in **Figure 1**.

For this reason, the following fundamental questions arise in this context:

- Is *one* set of societal preferences a reliable basis for choosing the best alternative? Can choice be excluded by chance?

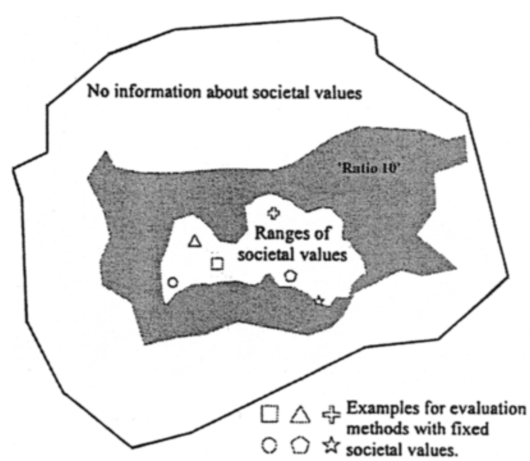

Fig. 1: Possible sets of societal values for weighting in LCA

[3] This term is quite different from the normalisation as used in ISO 14041 referring to process data in the inventory.

- Can acceptance of the results in society be high if only specific preferences are taken into account?

2.6 Distribution of societal preferences

In order to avoid choice by chance and to increase acceptance amongst the decision-makers, one particular mean weighting set is substituted by a distribution of potentially relevant societal preferences. As a first approximation, a uniform distribution is chosen with upper and lower boundaries given by the most extreme societal values as encountered empirically. Uniform distribution seems to be suitable as long as the level of information concerning societal preferences is relatively low (LUNDIE, 1999, pp. 199ff.). In the case of a higher level of information, other distributions, e.g. normal distribution, might be chosen.

Consider an LCA of different alternatives and each alternative makes a contribution to a number of impact categories. For each impact category, the upper and lower societal preferences is known from a survey. Between these extremes a uniform distribution per category is assumed. Based on this, all possible weighting sets in the given ranges can be calculated. These weighting sets represent all societal preferences in the given ranges which an LCA practitioner may find acceptable. All sets can be applied to the environmental data of each alternative. Then a statement can be made about resulting ranges of environmental scores per alternative. Furthermore, a relative statement about the frequency of the alternative ranking is possible.

3 Application of the Proposed Method

In this chapter, the proposed method is applied to an LCA about TV housings. The environmental impacts caused by different housings are combined with uncertain societal preferences recorded in a survey.

3.1 Case Study – four TV-housing concepts

Four existing TV-housing concepts are considered. Differences between the alternatives exist in the materials used, varnish and additives, production processes, and recycling possibilities (BEHRENDT et al., 1997). A brief description of the alternatives is given in **Table 1**.

Table 1: Characteristics of four TV-housing concepts based on BEHRENDT et al. (1997)

	materials	weight [kg]	use of flame-retardants
Alternative 1	high impact polystyrene	3.5kg	no
	noryl	3.1kg	yes
Alternative 2	high impact polystyrene	5.6kg	no
Alternative 3	steel	18.4kg	no
Alternative 4	steel	7.8kg	no
	wood	3.1kg	no
	aluminium	0.8kg	no

Flame-retardants used for the back of housing Alternative 1 reduce the possibility of recycling. Flame-retardants, often of unknown composition, have a negative influence on recycled material characteristics. Moreover, they can cause the formation of dioxins and furanes when burnt. Alternatives 2 to 4 contain no flame-retardants. All alternatives make a contribution to six impact categories: global warming potential, nutrification potential, acidification potential, photochemical oxidant creation, human toxicity and energy depletion.

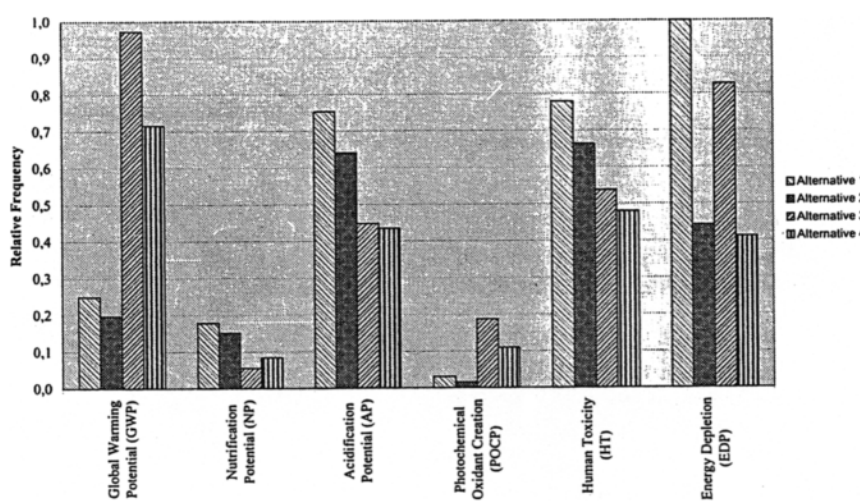

Fig. 2: Normalised impact category data

In BEHRENDT et al. (1997, p. 256), alternative 2 has been chosen as the best alternative on a qualitative basis. However, further information concerning the whole alternative ranking could not be deduced.

For reasons of transparency of the decision-making process, the data are normalised in proportion to global contribution per year per impact category (GUINÉE, 1995, p. 135). Additionally, the numbers are scaled on a linear basis to the largest absolute number in order to facilitate the application of decision-making methods (LUNDIE, 1998, pp. 151-162). The contribution to global warming potential, acidification potential, human toxicity, and energy depletion is relatively high, while the contribution to nutrification potential and photochemical oxidant creation is small (→ *Fig. 2*).

3.2 A survey on preferences

There is no general survey on preferences with regard to impact categories. However, a number of surveys are available (→ *Chapter 2.5*). In two cases where we have individual scores available (HUPPES et al., 1997; LUNDIE 1998) the "Ratio 10" is not exceeded. The central values, of course, converge much more closely.[4] Clearly more research is needed here.

In this survey (LUNDIE, 1998, pp. 175-178), ten decision-makers were questioned. All decision-makers, related to different interest groups (e.g. scientific institutions, enterprises, Federal Environmental Agency), were participants in the LCA of TV sets (BEHRENDT et al., 1997). This non-representative survey was based on the Delphi method. It consisted of two rounds: based on criteria of substainability and a detailed description of impact categories, the decision-makers were asked to express their preferences in percentages on these impact categories. In a second step, the results of the first round were presented to the decision-makers again. This time the decision-makers were asked if – with knowledge of the first round – they still insisted on their first weighting or wanted to change it (→ *Fig. 3*).

As shown in **Figure 3**, there are ranges of preferences concerning the importance of impact categories. No consensus was reached. Global warming potential, human toxicity and energy depletion seem to be more important than nutrification potential, acidification potential and photochemical oxidant creation. Apparently, the more an environmental issue is discussed in public, the broader the ranges of preferences. The outcome might differ depending on the representativeness of the decision-makers asked and their opinion, and skills concerning the judged environmental issues (LUNDIE, 1998, pp. 107-109). Generally, the outcome of the survey corresponds qualitatively to other inquiries related to environmental problems (HUPPES et al., 1997; HERRCHEN and KLEIN, 1994; WALZ, 1996).

The upper and lower preference boundaries of each impact category, however, are assumed to be the most extreme societal preferences for the decision-makers asked. For the application of the proposed method, the following intervals have been used in percent: global warming potential 15 to 40, nutrification potential 5 to 20, acidification potential 5 to 15, photochemical oxidant creation potential 10 to 20, human toxicity 10 to 35, and energy depletion 10 to 30.

[4] These were not representative or well-informed people, so that one might object.

[5] HEIJUNGS points out that the given preferences of impact categories are *not* independent of each other computationally (HEIJUNGS (1998), oral statement). In value terms, however, they are.

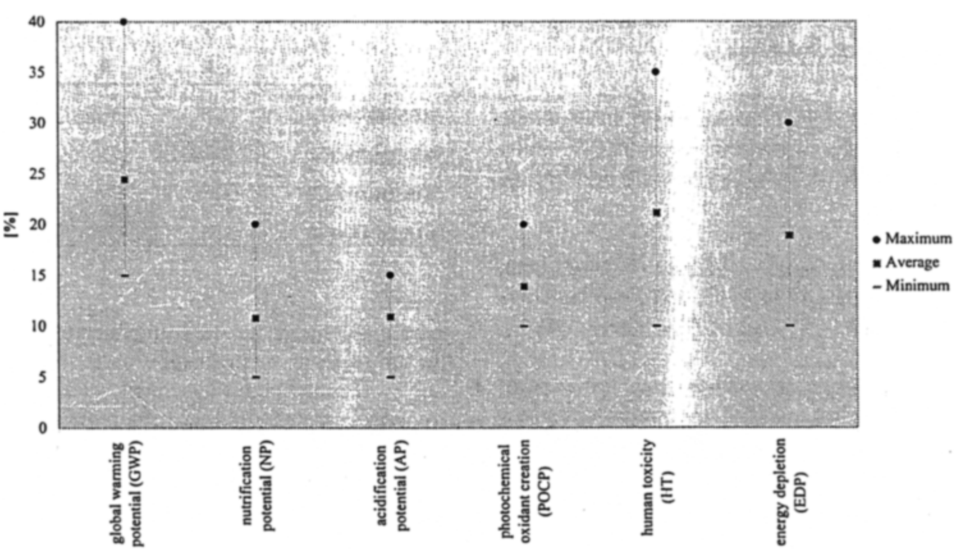

Fig. 3: Average and spread of weight in survey on six impact categories[5]

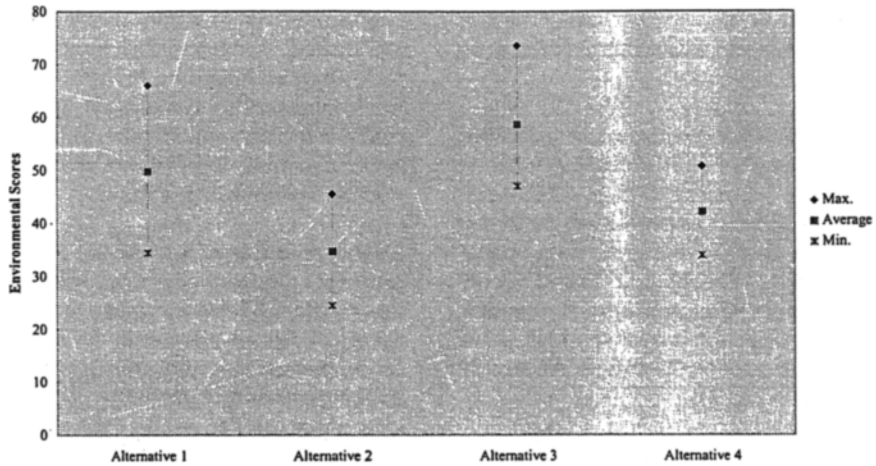

Fig. 4: Environmental scores of four alternatives based on weighting intervals

3.3 Combination of environmental profiles with ranges of societal preferences

As a first step, all possible weighting sets are calculated on the basis of uniform distributions within the range for each impact category. By choosing a step width of 5%-points, there are more than 700 weighting sets, each totalling 100%-points. A smaller step width enlarges the number of possible weighting sets in an exponential manner while the qualitative statement does not change. In order to avoid unnecessary calculation problems, the larger step width has been chosen.

3.3.1 Environmental scores

Each weighting set is applied to the environmental profile of the alternatives (→ *Fig. 2*). Figure 4 shows the ranges of environmental scores for each alternative.

The environmental scores of *all* alternatives are in the range of 24 and 73. Theoretically, a maximum score of 100 and a minimum of 0 is possible as long as the same method of normalisation is chosen.

Looking at mean scores, Alternative 2 seems to be preferable, with an environmental score of 34.8. It is followed by Alternative 4 (42.2), Alternative 1 (49.9), and Alternative 3 (58.6).

The ranges of environmental scores differ: Alternative 4 and Alternative 2 have narrow intervals of environmental scores, while the ranges are broader for Alternatives 1 and 3.

Only one unambiguous statement can be extrapolated from Figure 4: the environmental scores of Alternative 2 are always smaller than those of Alternative 3. Based on any societal preference, Alternative 2 is better than Alternative 3.

Further clear statements are uncertain because of the overlapping of environmental scores. Moreover, the scores are *not* independent. A high score of an alternative can be linked with a low score of another one. For example, a clear statement about Alternatives 1 and 2 is not possible based on Figure 4. But with the knowledge of Figure 2, Alternative 2 always has a lower environmental score than Alternative 1, a result of the partial dominance. Therefore, additional analysis has to be performed.

3.3.2 Rank order

As mentioned above, environmental scores per alternative

Table 2: Frequency of rank order based on weighting intervals

	Rank			
	1	2	3	4
Alternative 1	0%	14%	71%	15%
Alternative 2	95%	5%	0%	0%
Alternative 3	0%	0%	15%	85%
Alternative 4	5%	81%	14%	0%

are dependent on the weighting set chosen. In order to avoid the impression of precision created by such scores, these scores of each weighting set are ranked. Thus it is possible to make a statement about the frequency of rank order. In Table 2 the alternatives are listed according to their relative attractiveness in terms of rank order. The sum of frequency per rank and per alternative is 100.

The following specific statements can be deduced (Table 2 should be read by column):

Rank 1: Only Alternatives 2 and 4 can score best. With a probability of 95%, Alternative 2 has the best scores, while Alternative 4 is preferable in 5%.

Rank 2: Alternative 4 supplies 81% of the second best scores. In 5%, Alternative 2 is second best - this is valid for weighting sets which generate best scores for Alternative 4. Alternative 1 is second best in 14% of the weighting sets.

Rank 3: Approx. 71% of the third best scores belong to Alternative 1. Alternative 3 generates 15% and Alternative 4 14% of this rank.

Rank 4: Alternative 3 has the highest probability for rank 4 with 85%. Alternative 1 scores worst in 15%.

The frequency per rank and per alternative indicates how many percent of the decision-makers would agree on the alternative ranking within the given range of weighting intervals.

3.3.3 "Ratio 10"

If no survey is available, "Ratio 10" could be applied. By using intervals from 5 to 50% per impact category environmental scores can be calculated. The qualitative statement, deduced from **Figure 5**, is comparable with the statement from **Figure 4**. However, no unambiguous statement can be derived. The overlap of environmental scores is caused by much broader intervals.

Analysing the alternatives according to their relative attractiveness in terms of ranking (→ *Table 3*), the following conclusions can be drawn:

Rank 1: Alternative 2 is still the best with a probability of 56%. Alternative 4 is preferable in 44%.

Rank 2: All alternatives can be second best. Alternative 4 demonstrates 44% of the second best scores, while Alternative 2 generates 40%, Alternative 1 11%, and Alternative 3 5% of the second best scores.

Rank 3: At present, Alternative 3 is third best (49%). Alternative 1 generates 35%, Alternative 4 12% and Alternative 2 4% of this rank.

Rank 4: Alternative 1 has the highest probability with 54%, while Alternative 3 scores worst in 46%.

Table 3: Frequency of ranking based on "Ratio 10"

	Rank 1	Rank 2	Rank 3	Rank 4
Alternative 1	0 %	11 %	35 %	54 %
Alternative 2	56 %	40 %	4 %	0 %
Alternative 3	0 %	5 %	49 %	46 %
Alternative 4	44 %	44 %	12 %	0 %

The resulting statement is naturally weaker, but used intervals are much broader. Concerning the best and second best alternatives, the conclusions are the same, but Alternative 3 seems to be preferable to Alternative 1.

"Ratio 10" can be assumed as the broadest basis of societal values which contains all values of individual decision-makers of a group and/or a society. It can be used as a first assessment.

4 Stepwise Method for Environmental Evaluation

Based on the application of decision-making methods and ranges of societal preferences, a step-by-step approach in practice might help to evaluate given alternatives. This pragmatic approach consists of the following steps:

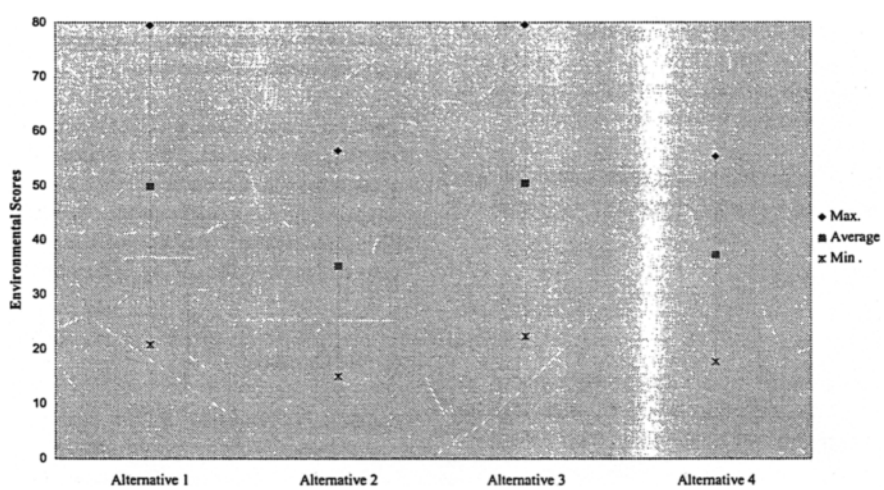

Fig. 5: Environmental scores of four alternatives based on ratio 10

1. Check the environmental profiles of full and partial dominance. In the case of full dominance, the dominating alternative is the very best or the dominated alternative is worst. Partial dominance fixes the attractiveness of these *particular* alternatives.

2. Apply "Ratio 10" to the environmental profiles by
   - calculating environmental scores and
   - ranking.

   "Ratio 10" permits a clear statement if there is no overlap of environmental scores or if the frequency per rank is higher than a certain border. The border is fixed by the decision-maker, e.g. 70%. In this case, Step 3 is not necessary.

3. Apply recorded societal preferences on the environmental profiles by
   - calculating environmental scores and
   - ranking.

   Clear statements are deduced according to Step 2. If the outcome of Step 3 does not satisfy the requirements of the decision-maker, no clear choice can be made.

5 Results

Data on the environmental impacts of TV housings and on a social preference survey have been used here. By applying the preference ranges method, a statement concerning environmental scores and a quite clear ranking of alternatives could be deduced. If no information about societal preferences is available at all, "Ratio 10" can be used as a first approximation of alternative ranking. Analysing the environmental scores (→ *Fig. 4*), Alternative 2, for example, is better than Alternative 3 for all weighting sets.

A more detailed statement about the ranking of the other alternatives is necessary. Based on ranges from a survey Alternative 2 was preferred in 95% of the cases as the most environmentally friendly product alternative. Alternative 4 scored best in 5% of the cases. Furthermore, Alternative 4 is second best with 81%, followed by Alternative 1 at Rank 3 (71%) and Alternative 3 at Rank 4 (85%). This ranking is in line with the application of mean societal values, but it takes the uncertainty of societal values into account.

By applying "Ratio 10" a similar qualitative statement can be achieved. However, the outcome is weaker as a result of the broad intervals.

5.1 Conclusions

The proposed method supplies a step-by-step decision-making support based on different levels of information. The environmental decision can be deduced step-by-step:

- at the level of pure environmental data (full/partial dominance),
- the "Ratio 10"-based set of environmental scores (ratio scale), or ranking (ordinal scale)
- a survey-based set of scores and rankings.

For many applications a decision on rankings is most likely. This methodological approach makes it possible to make a prediction concerning the relative (dis-)agreement with the choice of the best alternative in a society. The prediction can be based on "Ratio 10"-constraint or on a survey. A strong statement is frequently possible even if the given ranges of societal values are relatively large. The level of relative (dis-) agreement differs, depending on the case.

Even when using survey data on weights, no fixed societal preferences are needed. Instead, consensus-oriented weighting-intervals are used. This might speed up the decision-making process in LCA because weighting factors are often controversial. A choice by chance is always excluded when using the ranges of preferences method.

There are evaluations possible where an Alternative A scores best slightly at more than 50%, while an Alternative B has high scores at "a bit less" than 50%. Without further information, no conclusions can be drawn. Both alternatives should be considered as equally "good" or "bad".

Furthermore, the acceptance by participating decision-makers is probably higher because all individual weighting sets are included in the final order.

5.2 Discussion

This approach makes it possible to deduce a highly accepted ranking of alternatives based on intervals of societal preferences. If an accepted set of societal preferences, e.g. for the Netherlands, Europe, or the world, concerning all relevant impact categories could be deduced, an evaluation and recommendation in LCA could be simplified. Time-consuming processes of weighting with several sets of weights could be avoided. We do not expect this situation to evolve; although we expect that uncertainty in values and preferences will remain.

There are more uncertainties than on societal values in LCA. The validity and reliability of the empirical analysis in LCA inventory and characterisation, always limited and mainly unspecified, is another source of uncertainty. An analysis of both, uncertainty on data and uncertainty on values, would help to classify the quality of final LCA results.

6 References

Baumann, H., Rydberg, T.: Life Cycle Assessment: A comparison of three Methods for Impact Analysis and Valuation, in: Rydberg, T.: Improved Environmental Performance of Products – Halocarbon Substitution, Packaging Development and Life Cycle Assessment, Göteborg 1992

BEHRENDT, S., KREIBICH, R., LUNDIE, S., PFITZNER, R., SCHARP, M.: Ökobilanzierung komplexer Elektronikprodukte – Innovationen und Umweltentlastungspotentiale durch Lebenszyklusanalyse, Springer Verlag, Heidelberg 1997

Deutsches Institut für Normung (DIN), NAGUS-AA 3/UA: Grundsätze produktbezogener Ökobilanzen, German "Memorandum of Understanding": Sonderdruck aus DIN-Mitteilungen + elektronorm 73, Nr. 3, p. 208-212, 1994

EDWARDS, W., NEWMANN, J.R.: Multiattribute Evaluation. Series: Quantitative Applications in Societal Science, No. 26, Sage University Paper, 1982

FAVA, J., CONSOLI, F.J., DENISON, R., DICKSON, K., MOHIN, T., VIGON, B. (eds.) (1992): Conceptual Framework for Life Cycle Impact Analysis. SETAC and SETAC Foundation for Environmental Education. Workshop Report, 1.-7. February, Sandestin, Florida

GÄFGEN, G.: Theorie der wirtschaftlichen Entscheidungen. 3. Aufl., J.C.B. Mohr, Tübingen 1974

GUINÉE, J.B.: Development of a Methodology for the environmental Life Cycle Assessment of Products with a Case Study on Margarines, Proefschrift, CML, Leiden 1995

GUINÉE, J.B., HEIJUNGS, R. (final editor), HUPPES, G., LANKREIJER, R.M., UDO DE HAES, H.A., WEGENER SLEESWIJK, A.: Environmental Life Cycle Assessment of Products, Guide and Background, CML, Leiden 1992

HEIJUNGS, R.: Valuation: A Societal Approach. In: Udo de Haes, H.A., Jensen, A.A., Klöpffer, W., Lindfors, L.-G.: Integrating Impact Assessment into LCA, Proceedings of the SETAC-Europe Congress, 11.-14. April 1994, Brussels 1994

HERRCHEN, M., KLEIN, W.: Aktuelle Diskussion zur Methodik der Wirkungs-Ökobilanzierung – ihr Einsatz in der Abfallwirtschaft. In: Fleischer, G.: Produktionsintegrierter Umweltschutz, EF-Verlag für Energie- und Umwelttechnik GmbH, Berlin 1994

HOFSTETTER, P.: Towards a structured aggregation procedure. In: Braunschweig, A., Förster, R., Hofstetter, P., Müller-Wenk, R.: Developments in LCA Valuation, IWÖ – Diskussionsbeitrag, Nr. 32, Zurich 1996

HUPPES, G., SAS, H., DE HAAN, E., KUYPER, J.: Efficient Environmental Investments, Paper presented at the SENSE International Workshop: Environmental Analysis and Economics in Industrial Decision Making, Amsterdam 1997

HWANG, C.-L., YOON, K.: Multiple Attribute Decision Making, Methods and Applications, A State-of-the-Art-Survey, in: Lecture Notes in Economics and Mathematical Systems, No. 186, Springer-Verlag, Berlin Heidelberg New York 1981

International Organization for Standardization ISO 14040: Environmental management – Life Cycle Assessment – Principles and framework. Draft International Standard, ISO/TC 207/SC 5, 1996

International Organization for Standardization ISO/WD 14042.1: Environmental management – Life Cycle Assessment – Life Cycle Impact Assessment, ISO/TC 207/SC 5, 1997

LINDFORS, L.-G., CHRISTIANSEN, K., HOFFMAN, L., VIRTANEN, Y., JUNTILLA, V., HANSSEN, O.-J., RÖNNING, A., EKVALL, T., FINNVEDEN, G.: Nordic Guidelines on Life Cycle Assessment, Report Nord 1995:20, Copenhagen 1995

LUNDIE, S.: Ökobilanzierung und Entscheidungstheorie – Praxisorientierte Produktbewertung auf der Basis gesellschaftlicher Werthaltungen. Springer Verlag, Heidelberg, Berlin 1998

MILLER, G.A.: The Magic Number Seven, Plus or Minus Two: Some Limits on Our Capacity for Processing Information- In: Alexis, M., Wilson, C.Z. (ed.): Organizational Decision Making, 3. Aufl., Englewood Cliffs, New Jersey 1967

NOTARNICOLA, B., HUPPES, G., VAN DEN BERG, N.W.: Monetary and Policy-Based Weighting Methods in LCA. Forthcoming article in: International Journal of LCA, Landsberg 1998

Society of Environmental Toxicology and Chemistry (SETAC): Life Cycle Assessment – Inventory, Classification, Valuation, Data Bases, Leiden workshop, Leiden workshop report, Leiden 1992

WALZ, R., HERRCHEN, M., KELLER, D., STAHL, B.: Impact Category Ecotoxicity and Valuation Procedure – Ecotoxicological Impact Assessment and the Valuation Step within LCA – Pragmatic Approaches. In: International Journal of LCA 1(4), Landsberg 1996

WEBER, K.: Mehrkriterielle Entscheidungen, Oldenbourg Verlag GmbH, München 1993

YOON, K.P., HWANG, C.-L.: Multiple Attribute Decision Making – An Introduction, Sage Publications, Thousand Oaks 1995

Addendum

SETAC LCA Workgroup: Data Availability and Data Quality by Rolf Bretz, in: Int. J. LCA 3 (3) 121-123 (1998)

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